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# Studies of Plastic Insulators under Shock Conditions

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## Abstract

As experiments done with explosively driven switches and magnetic flux compression generators become complex, the details become increasingly important. In most experiments the detonation of explosives is done through layers of material that include metal and plastic, which may retard the detonation, and at the same time the insulating materials must maintain their integrity at high voltages. We have initiated some small-scale experiments that use a few hundred grams of explosives to study effects on shocked materials. These studies look at effects on detonation through various materials as a function of their thickness, and will be compared with hydrodynamic computer modeling done with the MESA2D code. Another related series of experiments observed the voltage breakdown of insulators under shock conditions. In this set of experiments insulators made of polyethylene, Teflon and Mylar were placed between two electrodes and exposed to 120KV during a shock. The timing of the shock was determined from light produced at a flash gap. Photo-diodes coupled to optical fibers were used to transmit the signals to the diagnostic bunker. A Pearson probe was used to monitor the voltage at the insulator during the breakdown. The timing of the breakdown relative to the shock arrival time was recorded. The breakdown data as a function of materials and geometry are provided in this report. Also, these data are compared with computer simulations that may suggest material conditions at the time of insulator failure.

## I. INTRODUCTION

For several decades we have been working with explosively driven flux compression generators and switches. In recent years, the complexity of the experiments has increased and the experimental loads placed on these systems require that they be able to handle voltages above a 100kV at the 10 MA range and higher. The harsh environment, due to the explosives,

places stringent demands on the materials used in these experiments. Because insulators are very critical and necessary part of them, we demand that they survive to the completion of the experiment. Eventually, the insulators will fail and high voltage breakdown will take place. Our aim is to see how insulators respond in this extreme environment and from that determine how to better design the system to survive the harsh conditions. Geometry and materials both need careful consideration to minimize the probability for breakdown. We have devised a series experiments to look at the integrity of insulators subjected to shocks generated by the explosives and then measure the time to the electrical failure relative to the shock arrival time..

The insulators that are considered in this paper are Teflon, Mylar, and Polyethylene all in various geometries and conditions. It is not clear what the actual breakdown mechanisms might be but we will compare the timing of the breakdown with calculations of pressure and material location determined by a hydrodynamics code (MESA-2D). Others<sup>1,2</sup> have studied these materials and observed strange effects in resistivity but those experiments were not done at the voltages of our experiments. These experiments suggest that these materials are very complex and no simple answer can be attributed to high voltage breakdowns. To get a handle on the breakdown mechanism, future experiments should include measurement of resistivity during the shock and through the electrical breakdown and also to couple an electro-magnetics code to the hydrodynamic effects.

We have devised three sets of experiments that address the voltage breakdown issues. They all include electrodes at 120 kV placed around insulators in a variety of combinations with the explosives. The details will be shown in the experimental section. Another experiment was done to verify that the explosives still properly detonate as the shock transits through insulators and metals in geometries that are typical to our experiments. Many of our experiment have geometries that sometimes, unavoidably, include sharp metal edges, sometimes areas where explosives generate shear forces, and sometimes the materials act differently under shock conditions. All of these can cause disastrous problems in high voltages

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conditions. Our hope is that these simple experiments can provide us with enough insight, and confidence so that we can design better metal and insulator transitions where high pressure shocks and voltages are present.

## II. THE EXPERIMENTS

The experiments were done at Los Alamos National Laboratory at the explosives firing point in Ancho Canyon. A total of 21 experiments were done to study the voltage breakdown problems. Fig. 1 shows a diagram of the different types of experiments. In all these tests, an insulation package was sandwiched between two electrodes connected to 120 kV DC power supply. A shock wave produced by high explosive (HE) was passed through the sample, and failure of the insulation was indicated by current flow in the cable from the power supply. A flash produced in a flash-gap on the second electrode surface is sensed by a fiber optic probe and recorded to indicate the time of arrival of the shock. The electrical breakdown time for each test is referenced to that fiducial time.

The experiments depicted in figures 1a and 1b used circular pieces of PBX-9501 explosives (4.25in diameter and .5 in thick). The metal electrodes were 6 and 6.5 inches in diameter on top and bottom respectively. These experiments were to observe shock induced voltage breakdowns in insulators. We shall refer to these experiments as VCRIT.

The experiments shown in figures 1c and 1d have significantly more explosives. The aim was to add mechanical shear in addition to the shock to the experiments. Therefore we call these the SHEAR tests. These used a 10 inch diameter, one inch thick pieces of HE on the bottom, and an 8 inch diameter and one inch thick half cylinder on top. The positioning of the HE, metal electrodes and the line wave detonator were critically placed to closely match the geometry of what was used in the explosively driven opening switch. The experiment illustrated in figure 1c, had electrodes in planar geometry, and in 1d one electrode was oriented vertically. Both experiments were to simulate different conditions in the switch/generator geometry. The vertical electrode geometry would be considered poor electrical design but in practice this situation may be unavoidable.

All insulation packages were 24 inches square and varied in thickness, material type, and material form. Material form distinguishes from a solid material, or made of thin layers, or with layers laminated together. In our experiments only the polyethylene was laminated together and was made from 10 mil sheets with Sylgard 184 to make 1/8 and 1/4 inch thick packages. The tests in figure 1a and 1b used: 1/16 inch layered polyethylene; 1/8 inch solid, layered and laminated polyethylene; 1/4 inch solid and laminated polyethylene; and 1/4 inch layered mylar. For the tests where shear was introduced, the insulation package was 1/8 inch Teflon and 1/4 inch laminated polyethylene.

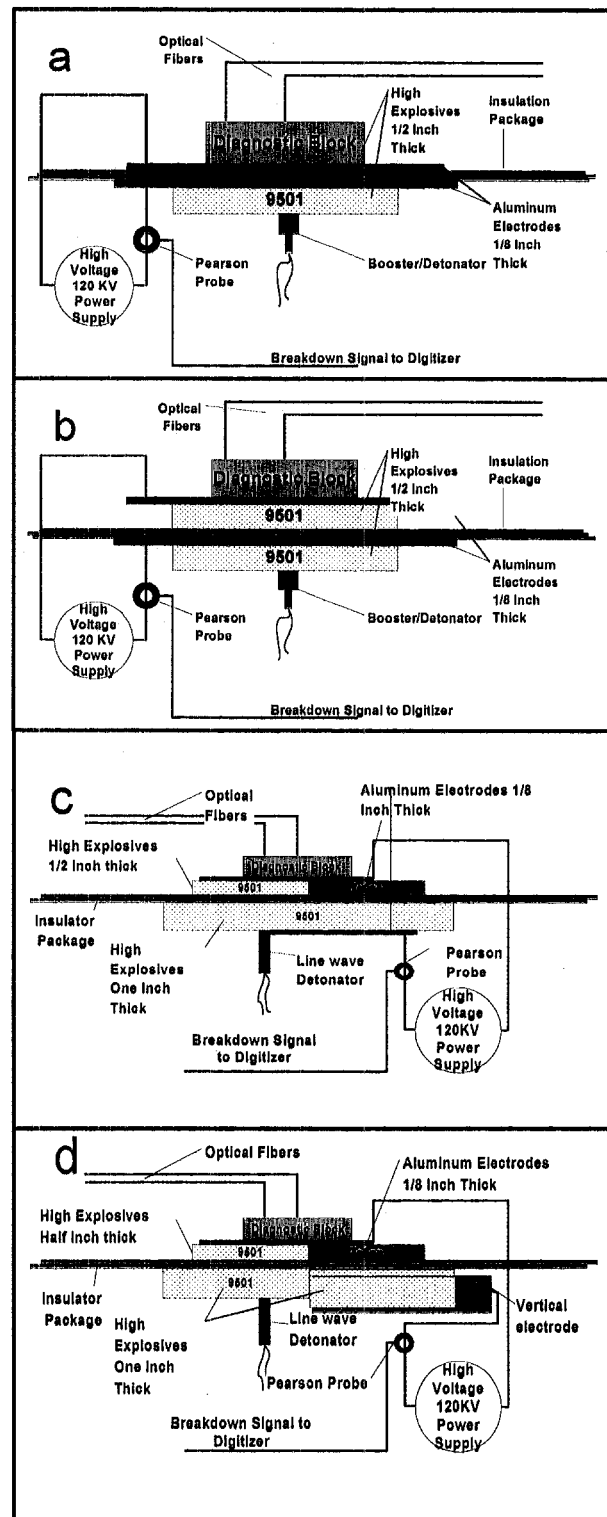
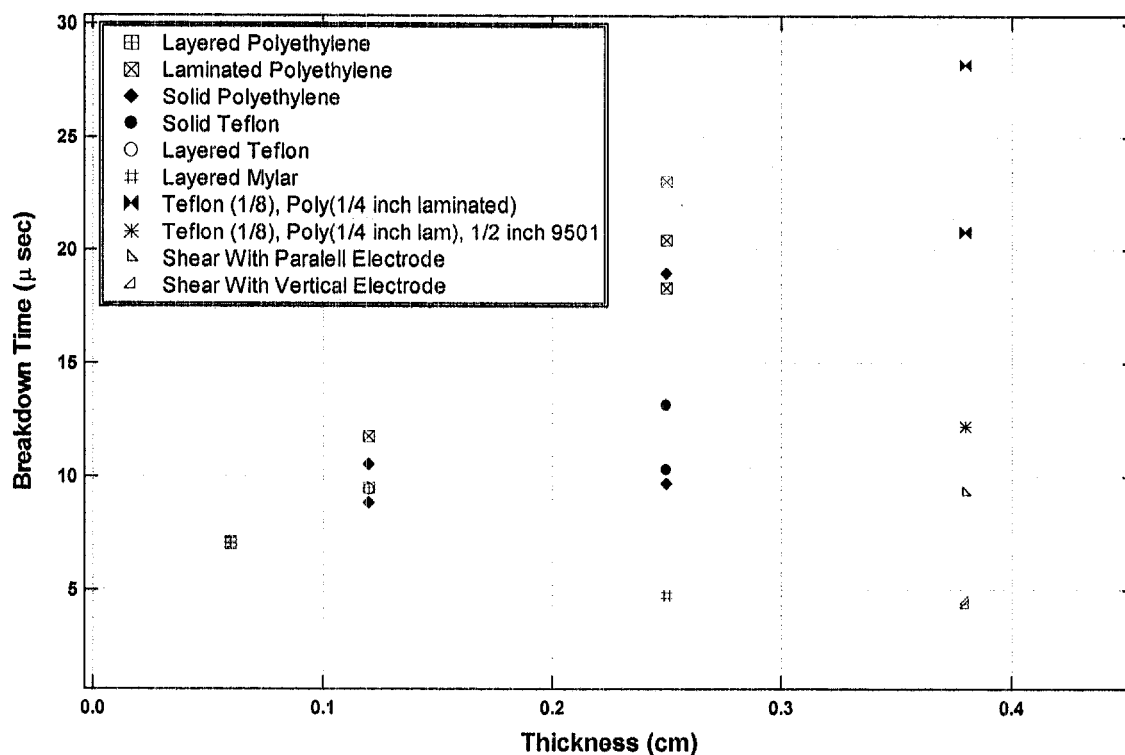


Figure 1 Shock Induced Electrical Breakdown Tests. Most experiments were configured as shown in (a). In (b) tests at higher pressure were done with the "HE sandwich". In (c) and (d) mechanical shear was addition to the shock and was done in two geometries. The breakdown was determined with a Pearson probe. The flash-gap in the "Diagnostic Block" provided the fiducial for shock arrival time.



**Figure 2** Compilation of VCRIT an SHEAR data. The insulator failure time is plotted against nominal insulator thickness. Insulator type and experimental conditions are given in the legend.

The "Diagnostic Block" incorporates the flash-gap and optical fibers. Fused silica fibers, .5mm in diameter and 20 meters long, were used to transmit the light from the flash-gap to the bunker and photodiodes. The flash-gap was a 13 mil air space in front of the fiber. Air in this space would flash at shock arrival time. On a previous experiment a calibration of the optical pins was done relative to quartz piezo pins and we found a insignificant but consistent difference in shock detection time. We did not use the quartz pins because they would have required direct electrical connection to the high voltage electrode at 120kV and to the digitizers. This would have compromised the experiment. Two fibers pins were used, one geometrically above the detonator, that provided the fidutial, and the other two inches away. The other fiber pin was mainly for backup purposes but did provided useful shock arrival time information for testing the hydrodynamics code.

### III. DATA

A compilation of all the data for both the VCRIT and SHEAR tests are shown figure 2. The time to electrical breakdown is given on the vertical axis and the nominal insulator thickness on the horizontal axis. Characteristics of the insulators and the experiment type are given in the legend.

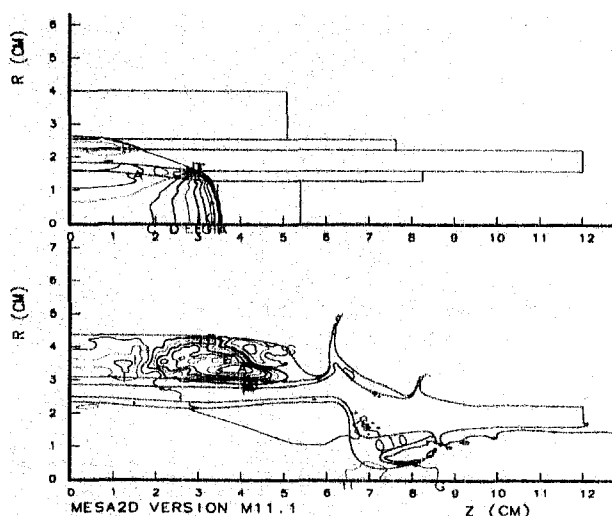
Purpose of these tests was to confirm/deny previous knowledge regarding electrical breakdown properties of insulators in high shock strength environments. The best

insulation, in any thickness category, is laminated 10 mil polyethylene sheets. On the average bulk or solid polyethylene samples tend to break down sooner. One might think that completely flawless bulk sample will behave like the laminated sample, but most bulk samples are not flawless and fail early.

For tests with Teflon, we acquired the highest quality, and always considered it as a very good insulator. We thought this was one of our best choices in the explosive environment. However quarter inch samples of it fail quite a bit earlier than bulk polyethylene. It was not possible to do the shock tests with 1/8 inch Teflon. They failed before full voltage was placed on the electrodes one failed at 50kV and the other at 75kV.

According to our tests, the best samples were laminated polyethylene and the worst ones were mylar, and to our surprise, Teflon. The layered polyethylene, in most cases did slightly better than solid or bulk polyethylene.

As expected, the tests in the shear configuration failed earlier than in the vcrit configuration. Since more explosives are used in the shear tests, a test was needed to distinguish breakdown between higher shock pressures on the insulator or failure due to actual mechanical shear. For this test an explosive "sandwich" was made as seen in figure 1b. This was composed of the same insulation package (1/4 inch laminated polyethylene and 1/8inch Teflon) as was used on the shear tests. The results were that the extra 1/8 inch of Teflon improved the insulation package just slightly as compared with vcrit test that had only 1/4 inch laminated polyethylene. The HE "sandwich" test failed much earlier than this vcrit and the planar shear



**Figure 3 Vcrit tests. Shows MESA-2D analysis at the time shock hits the "Diagnostic Block" (top), and at time of the electrical breakdown (bottom). Material interfaces and pressure contours are shown.**

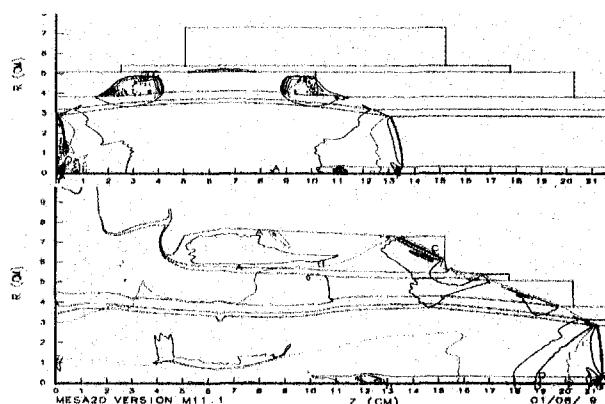
test (figure 1c), failed even earlier. Therefore, at least partially, the hydrodynamic effects of shear are enhancing electrical breakdowns.

Two tests were conducted with a vertical electrode in the "shear" geometry (figure 1d). Both tests showed a failure time of about  $5\mu$  seconds earlier than the experiment with the parallel electrodes and about  $10\mu$  seconds earlier than the HE sandwich test. It is obvious that designs that incorporate such features must be avoided.

In order to aid in the design for better experiments and help determine breakdown mechanisms, we have analyzed each of these tests with MESA-2D. This code shows pressure contours, location of material interfaces, the material density, material velocity and most other hydrodynamic properties, and all are seen as the experiment progresses. No obvious features that correlate with electrical breakdowns were seen. However, animating the pressure contours on the computer suggested that breakdowns appear soon after a rarefaction wave enters the insulator.

Figures 3 and 4 show sample outputs from this code. Due to limited space, we will show analysis from two experiments. Figure 3 shows a vcrit test that had 1/4 inch polyethylene insulation. The top frame shows material interfaces and pressure contours at shock arrival time. At the bottom, material interfaces and pressure contours are shown at the electrical breakdown time. The code has the detonation point at the origin and assumes symmetry about the y-axis. The shock arrival time for this test is at  $4\mu$  seconds after detonation. Approximately  $20\mu$  seconds after that, as determined from the experiment, the breakdown happens.

Figure 4 shows a sample from the shear test. Again a view of the material interfaces and pressure contours are seen at shock arrival time. At the bottom, during electrical breakdown time, violent material motion, electrode jetting and insulator warping are observed. At this time a rarefaction wave is passing through the



**Figure 4 The shear test. Shock hits diagnostic block (top). Material interfaces and pressure contours at breakdown time (bottom).**

insulator region. The code has provided important insight for experiments in this geometry. The analysis provides information regarding the issue of the precise run to detonation in the second layer of the HE. The calculations shown here use the nominal detonation parameters for the PBX-9501 explosive. Experience shows, however, that the run to detonation is not always predicted very accurately. In this problem the hydrodynamics in the shear region appear to be highly sensitive to these details. In this calculation, as seen on the top of figure 4, the run to detonation is a considerable fraction of the HE layer thickness. As a result, the detonation appears to be moving almost horizontally in the shear region. This provides a very different hydrodynamic scenario than if the detonation occurs promptly on the first shock. These calculations need to be correlated with excess transit time measurements but have not yet been performed in this configuration. However, we have done several tests in this series to confirm that the HE will still detonate as the shock goes through several layers of insulation and metal components. If needed, adjustments will be made to the detonation parameters to obtain the best picture of the degree of shear at breakdown time.

## IV. CONCLUSIONS

We have tested and compiled data about voltage breakdown conditions of several insulators in shock environments. We found that laminated polyethylene is the best that we tested and, to our surprise, Teflon was one of the worst.

Calculations were done with MESA-2D to help search for possible problems. We plan to continue these tests and use MESA-2D, MACH2 and other codes for guidance

## V. REFERENCES

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